EPANET2 DESKTOP APPLICATION FOR PRESSURE DRIVEN DEMAND MODELING

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Abstract

The fixed demand hydraulics engine of EPANET software in its original form is not suitable for analysis of water distribution networks with low operating pressures. A modification of EPANET desktop for pressure driven demand analysis, employing emitter modeling of demands, is presented. The introduced version is able to work in a fully transparent way with standard EPANET network files and could be developed into other EPANET-toolkit based applications following the exact procedure as with standard EPANET. A simple network example used to demonstrate the operation of the system. Finally an illustrative case study of the model application is presented.

Keywords: EPANET, Emitter, Pressure driven demand, Intermittent water supply

1. INTRODUCTION

Under ideal operating conditions, water distribution networks have adequate operating pressure throughout the system, making the water withdrawal virtually independent of the system pressure – the demand is fully determined by the end-of-pipe, customer behavior. However, there are many practical situations where the operating pressure of the networks are less than ideal – due to excessive demand, among other reasons. Examples are contingencies like pipe breakage and day-to-day operation of many water networks of urban centers of the third world.

Ozger (2003) developed a semi-pressure-driven algorithm for network analysis that could circumvent the problem of spurious negative pressures due to forced-demand conditions in the hydraulic analysis. While being much more realistic compared to the standard demand-driven analysis, this approach had the weakness of withholding demands until the minimum service pressure is achieved. This is analogous to a situation where the customer volenteerly refrain from drawing water when the service-pressue is low. Cheung et al. (2005) implemented a pressure-sensitive demand version of EPANET using the object oriented modification of EPANET known as OOTEN and utilizing emitter functionality of EPANET. This was a command line tool, not integrated to a graphical user interface. Giustolisi et al. (2008), among others, have presented new numerical algorithms to handle pressure-dependent demand in networks.

We modifed the EPANET 2.0 computational engine to implement pressure-sensitive demand in network calculations, in a way that is completely compatible with the existing user interface of the standard EPANET model. Further the EPANET-toolkit applications using the demand-driven EPANET (standard) engine can benefit from this modified form without changing any application code.

2. THEORY

As explained in section 1, standard demand driven analysis first imposes the demands on the network and then analyses the resulting pressures. In a scenarios where the demand is fully dependent on pressure (e.g. Irrigation sprinkler system), the pressure-demand relationship is explained by an emitter formula that states demand is proportional to a fractional power of the pressure (normally this power, $\alpha = 0.5$ for nozzles). However, in reality, the behavior of network nodes that represent a collection of household customers is much more complex. When there is adequate pressure in the system, the customers decide the demands (hence the demand driven analysis works). When there is not 'adequate' pressure (P_{ECUP} – will be further discussed in section 6), the demand (Q) depends on customer decided demand (Q_o) as well as the current pressure of the system(P).

Hence, all demand nodes of a network that has converged to a stable condition under realistic PDA should satisfy the following conditions:

1. For $P > P_{ECUP}$, $Q = Q_0$
2. For $P < 0$, $Q = 0$
3. For $0 < P < P_{ECUP}$, $Q = SP^{\alpha}$

where S is a proportionality constant known as emitter constant.

3. SOFTWARE ARCHITECTURE

Attempts were made to design the software as straght-forward as possible to use by the end user as well as the toolkit-programmer. To ensure this, several principals were adopted during the development of the software:

1. Fully transparent EPANET toolkit calls. (e.g. The toolkit programmer need not worry about the customization, but can use the new library with standard toolkit calls.)
2. Possibility to fully integrate with EPANET Desktop interface. (So that the full power and ease of use of the Desktop interface can be used to setup, run and post-process models.)
3. Keep the changes within EPANET engine and Desktop interface to a minimum. (So that it is possible to upgrade the system with possible future EPANET versions.)
4. To make, as large portion of the project as possible, reusable for different future projects related to customizing EPANET.

In order to achieve the above objectives, the development was divided to two distinct stages, namely

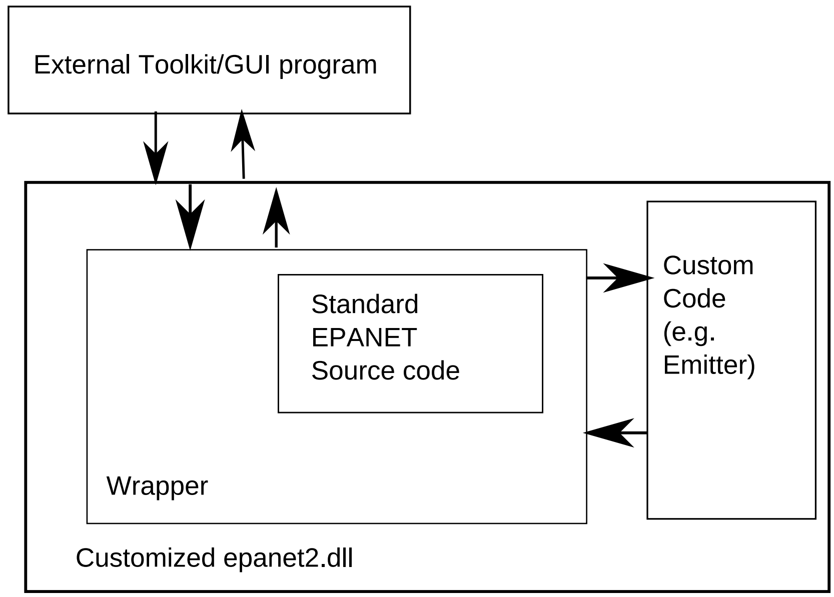

Figure 1: A block diagram of the customization scheme.

1. to build a wrapper for the standard EPANET engine, that allows to call a custom routine before execution of each toolkit call, and,
2. to develop the custom routines to implement emitter modification based on the above framework.

3.1. A wrapper for EPANET engine

The EPANET program (Rossman, 2000) is designed in two distinct components: The analysis engine and the entity that operates the engine, where the latter can be the Desktop interface or a customized toolkit code. This flexibility has allowed numerous adaptations of the engine code to be embedded in numerous other 3rd party tools in an elegant way. The two component communicates via a set of calls known as "toolkit-functions" (e.g. ENOpen, ENInitH, ENrunH, etc.). In the present modification, the task of the developed wrapper is to intercept these calls, first allow for running any custom code necessary to implement a modification and then pass the control to the EPANET engine. This architecture is explained in the block diagram in figure 1. An example of a call is shown in the sequence diagram in figure 2. The the user who develops the toolkit driver does not have to worry about the fact that she is dealing with a customized EPANET engine. The wrapper will simply intercept the toolkit call (ENopen), calls the custom function (run_before_ENopen) and then calls the ENopen of the original EPANET engine.

The above calling interface is provided as a static library, that could be compiled into a dynamic linking library after implementing the application logic. (See the example in section 3.2.)

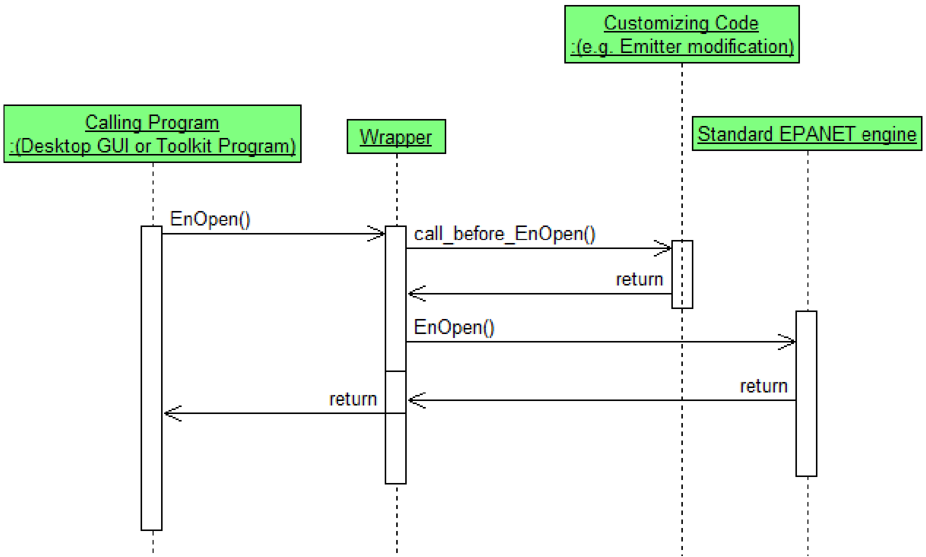

Figure 2: An example calling sequence.

3.2. PDD analysis

The process of pressure-based demand analysis is as follows:

1. Enable the standard emitter function at each node of the network.
2. Iterate through time, **for each time-step**,
3. Compute emitter parameters and replace all the demands with emitters.
4. Run the network using a call to standard EPANET.
5. Start iteration.
6. Check the pressure, demand conditions at each node (see section 2).
7. Adjust the node conditions (switching between emitters, fixed-demand and zero-demand, as appropriate) based on 6
8. Compare demand and pressure at each node with the previous analysis cycle.
9. **Repeat steps 5 to 8**, until all the conditions in 6 and 8 are satisfied.
10. Call standard EPANET with converged parameters. This run provides the final result for the current time-step.
11. Reset the original base-demands. Reset the emitters to zero.
12. **Repeat from 3** for the next time step.

This list of activities are performed within the framework of calling interface developed in section 3.1 as follows:

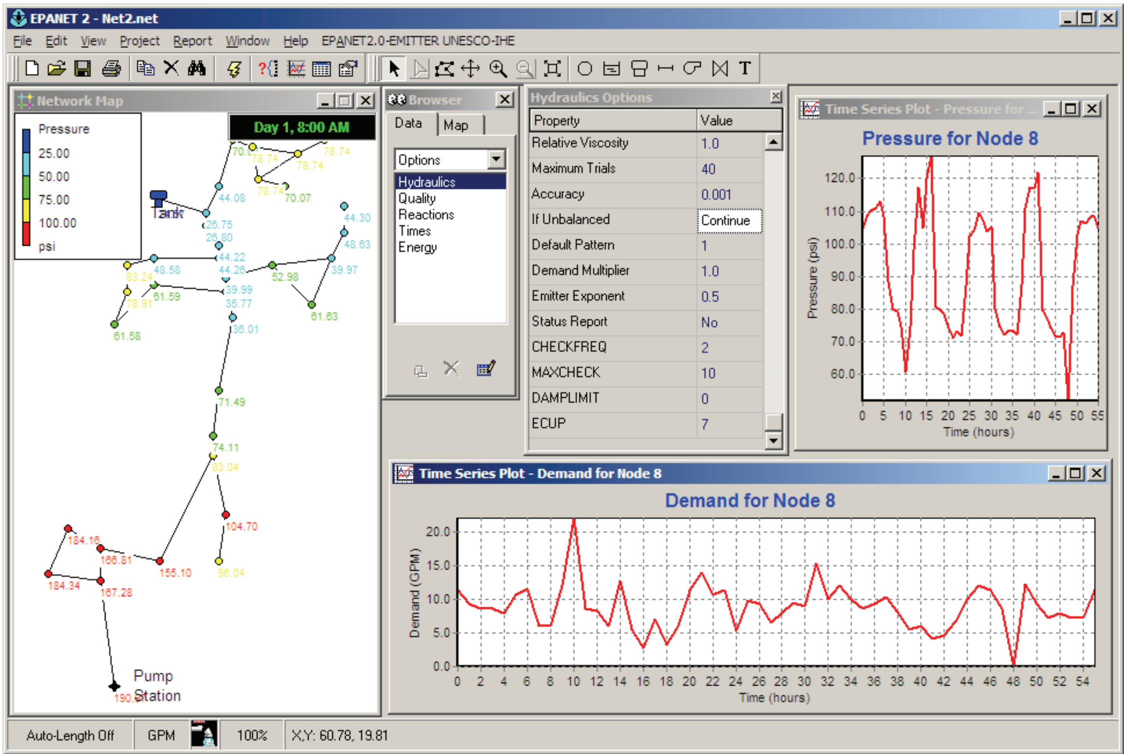

Figure 3: The analysis is fully integrated with the graphics desktop of EPANET. User specification of ECUP parameter is allowed.

Calling function	*Items implemented*
`run_before_ENinitH`	1
`run_before_ENrunH`	3–9
`run_before_ENnextH`	11
Implemented in standard EPANET run	2, 10, 12

3.3. The Graphical Desktop

The Graphical desktop of EPANET is written in a Delphi language (Wikipedia, 2008), a dialect of Object Pascal for Windows. The current modifications to the EPANET engine does not require a modified graphical desktop to work with the resulting dynamic link library (EPANET2.dll). However, a small enhancement to the graphical user interface was done in order to allow the user to change the value of P_{ECUP} (as parameter `ECUP`) as an analysis option. The parameter ECUP was also introduced to the EPANET network file format. Figure 3 shows the integrated desktop.

4. MODEL IN ACTION

Figure 4 is a comparison of nodal pressure and demand using standard EPANET version and the modified emitter version to a simple network. The network in this example is the same geometry

as the standard example file `Net1.net` provided with EPANET 2.0 software. A demand multiplier of 4 was applied to create a pressure deficient situation in the network. The units were converted from standard gallons per minute (GPM) to liters per second (LPS).

In the standard EPANET 2.0 software, the pressures drop to large negative values, attempting to maintain the hydraulic balance in the system. This is physically unrealistic. On the other hand, the emitter modified version has the emitters kick-in when the pressure is below $ECUP$, modulating the flow. This results in a more physically realistic flow situation. The value of $ECUP$ depends very much on the network properties like the nature of the nodal demands and level of simplification from the reality. Experience shows that this values is around 10m for networks with normal domestic demand.

In the next section we demonstrate the use of the software with an application.

5. APPLICATION: EXTENDING CUSTOMER MINUTES LOST CONCEPT

WaterNet (formerly Amsterdam Water Supply), the company managing the water supply of Amsterdam City (Waternet, 2010), use the average number of minutes water supply disruption due to repair activities per year per customer connection, termed as "Customer Minutes Lost (CML)" to benchmark its service levels. The repairs of major leakages and bursts are carried out by closing the 'value-section' that includes the problematic pipe and the impact on this activity on CML is calculated by the following non-hydraulic approach:

$$CML_i = N_{c,i} t_{d,i} \tag{1}$$

where CML_i (units: min) is the contribution to the Cml by the closure of a value section i. $N_{c,i}$ and $t_{d,i}$ are the number of customers connected within the value section i and the time period the section was closed for repair, respectively. CML for the network is calculated as the sum of Cml_i for a year for the whole network divided by the number of customer connections in the network.

However, it is obvious that the closure of an interconnected value section of a network could have impact not only for the customers within that valve section, but for others outside that section, due to changes in the network hydraulics. The network situation after a burst but before closure for repair can also contribute to the customer service levels. Three issues need to be resolved in order to consider these for a more realistic estimation of CML,

1. Impact on the customers outside the valve section could be the partial supply of water due to drops in the pressure. This requires the extending the definition of the CML concept.
2. Network hydraulics need to be taken in to account. There is the possibility of the network being under pressurized.
3. A representation of pipe bursts in the hydraulic network so that the before-closure situation can be simulated.

The CML concept was extended as follows: CML_m is the value of 'Customer minutes lost' computed by assuming each customer connection that received only m percentage (or less) of its required demand due to network disruptions. This necessitates the use of a network model that

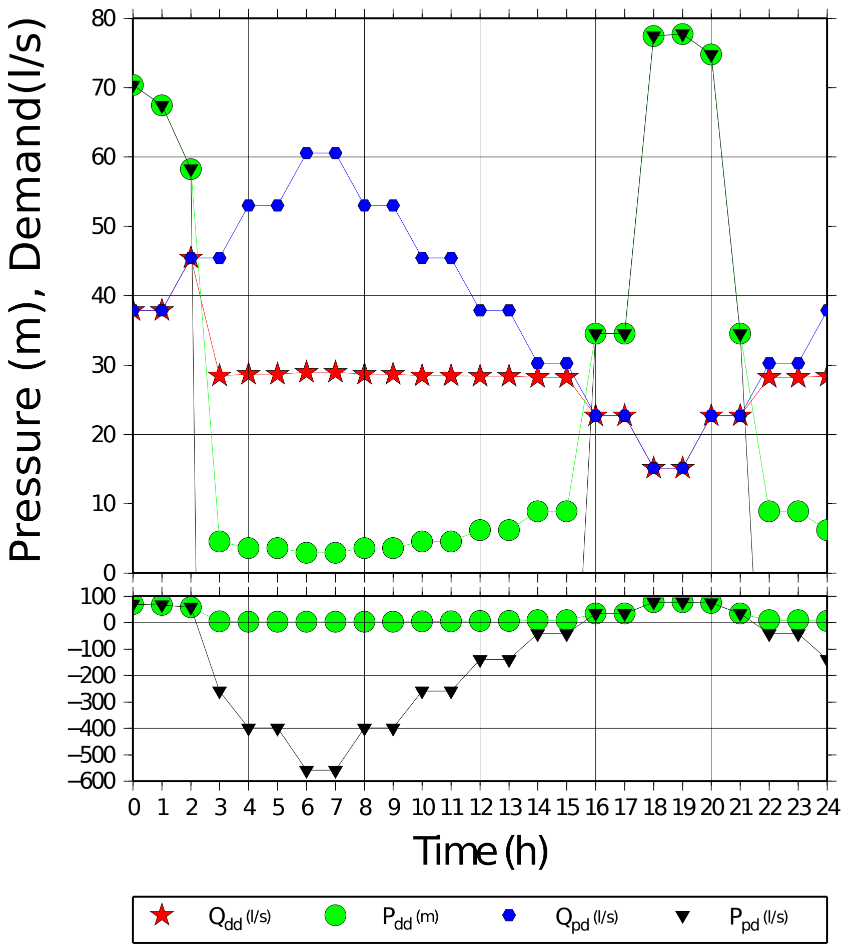

Figure 4: The EPANET standard example `Net1` (with a demand multiplier 4), analyzed with the emitter modification (Q_{pd}, P_{pd}). The standard EPANET results are also shown for comparison (Q_{dd}, P_{dd}). Results with standard EPANET is also shown for comparison. $ECUP = 10$m. Chart on top and bottom shows the same data in two different verticle scales.

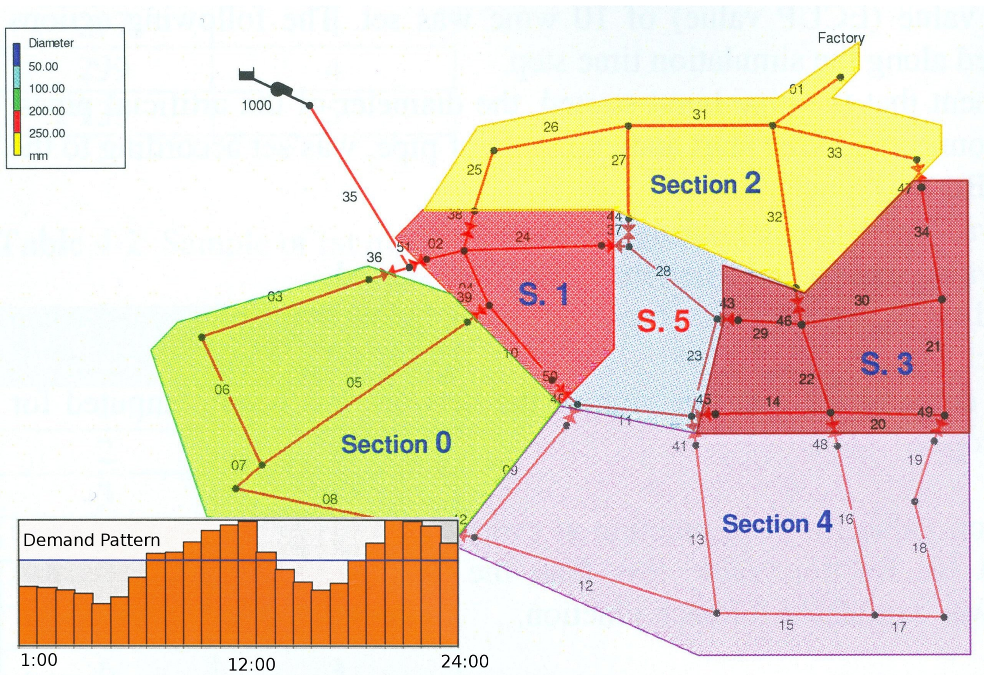

Figure 5: The Safi network. The diurnal demand pattern is shown on bottom left.

can represent the pressure-driven demand conditions. We used the emitter modified EPANET tool for this. A concept called 'Equivalent Burst Diameter (EBD)' was defined as a proxy for burst conditions. EBD is the diameter of the orifice that represent the one-half of the magnitude of the burst in hydraulic terms. Orifices of EBD diameter are introduced at the end-nodes of a pipe to represent a burst in that pipe.

The application of the concept is demonstrated below using a simple water distribution network known as 'Safi Network' (Trifunovic, 2006), consisting of six valve sections (Figure 5).

Figure 6 shows the CML_{80} and CML_5 values for the breakage of pipes with $EBD = 10\%$. The typical time between the event (burst) and isolation of the valve section was assumed to be 2h and the repair time 6h. These were typical values for Amsterdam water network. The difference between the two CML values indicate the customers who recieve some amount of water, but the service level (indicated by amount of demand satisfied) is substandard. It shold be noted that the specific values of the numbers 80% and 5% are largely arbitrary apart from the fact that the former indicates a 'satisfactory' service level while the latter indicates the customer recieves practically no water.

One of the interesting findings of the study was the fact that, for small bursts, sometimes it

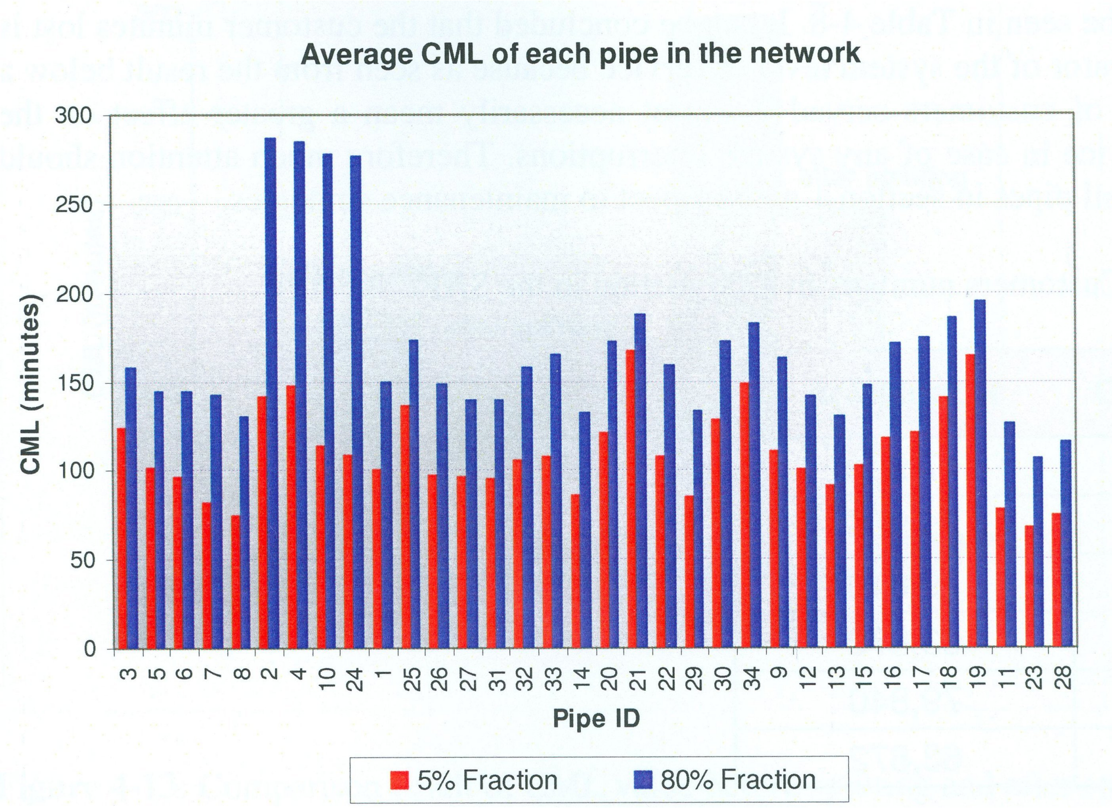

Figure 6: CML_{80} and CML_{80} for $EBD = 10\%$ failures.

is *beneficial* in terms of CML_m to delay the repair by several hours. This largely depends on the time of burst with reference to the demand pattern. For example, for a $EBD = 10\%$ burst in pipe 23 occuring at 10:00hrs, the CML_5 would be reduced by 10% by delaying the repir by 4 hours (figure 7).

6. DISCUSSION

The demand driven water transport and distribution model, EPANET 2 was modified to develop a pressure-sensitive demand version that is fully integrated to the standard graphical user-interface of the model. In the case of low-pressure, high-demand situations, the new modified model avoids the spurious negative pressures due to artificially fixed demands in the original EPANET model. In 'normal' situations where there is adequate pressure in the system, the new models results are virtually identical to those of standard EPANET 2.

Many of the water distribution networks of the cities in developing countries suffer from lack of operating pressure due to excessive demand conditions. It is impossible to use demand-driven models to reliably analyze the flow situation in these networks. In such situations it is hoped

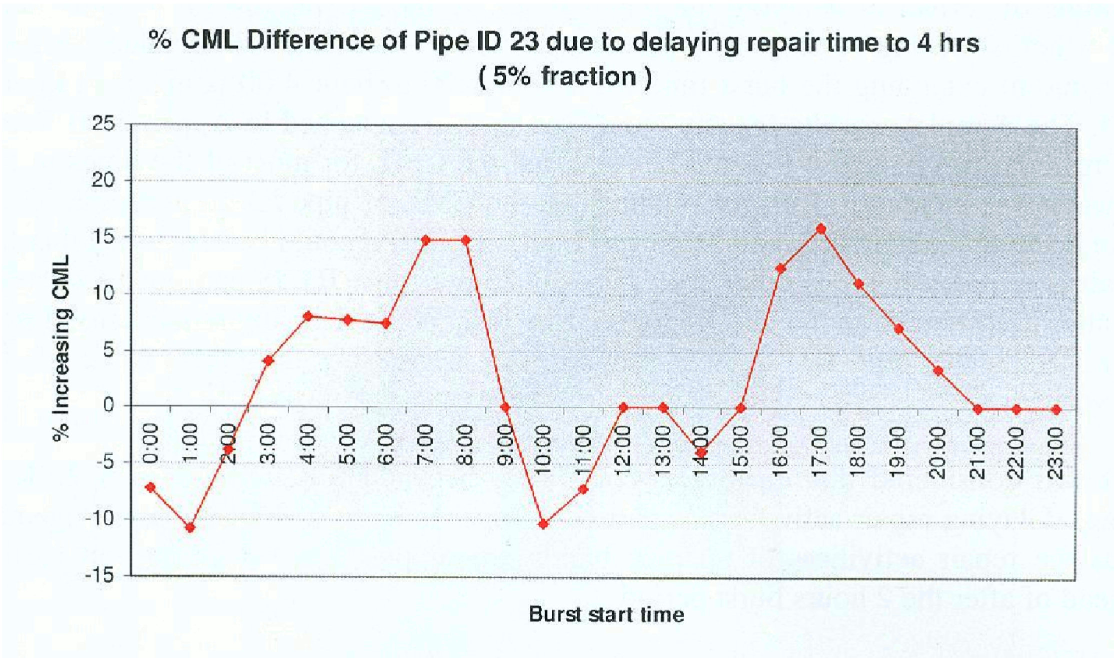

Figure 7: The impact on CML_{80} of delaying a repair by 4hrs. For bursts occurring at some particular time, the CML_{80} would be reduced by deferring the closure of the valve section.

that the new version will be helpful. Further, network analysis in contingency situations (e.g. pipe breaks) can also be more realistically achieved.

The current implementation has several drawbacks. First, it is not possible to specify different $ECUP$ and emitter exponent values for different nodes (or different demand categories) – clearly a technical limitation that can be readily overcome. Another, more serious issue is the inability of the model to realistically handle actual (as opposed to spurious) negative pressure conditions (e.g. unusually elevated node). In this situation, the model resorts to a situation of zero demand and negative pressure. In reality air should enter the network from the node until the pressure becomes zero (atmospheric). However, this is a complex situation that does not render an easy solution within the current model.

In order to validate the new model, it is necessary to apply it to situations where measured observations are available. This step is currently being done. It is also important to establish realistic values of emitter coefficients that could represent household and other demand conditions. This calls for further investigations.

The application of the modified-model in the case of analyzing a contingency situation, namely pipe-burst and repair activity's impact on customer minutes lost, shows the utility of the current model.

Note: The modified version is available for download at `http://assela.pathirana.net/EPANET/`. The program source code will be provided on request.

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